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External insulation with cellular plastic materials – thermal properties, long term stability and fire properties

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SUMMARY:

External thermal insulation composite systems (ETICS) can be used as extra insulation of existing buildings. The system can be made of cellular plastic materials or mineral wool. There is a European Technical guideline, ETAG 004, that describe the tests that shall be conducted on such systems. This paper gives a comparison of systems with mineral wool and cellular plastic, based on experience from practice and literature. It is important to look at the details in the system and at long time stability of the properties such as thermal insulation, moisture and fire. Investigation of fire properties must be done before utilisation of the system, including the risk of fire spread from one storey to the next for practical solutions. An elaboration of fire spread risks require thermo physic knowledge about ignition temperatures, critical radiation, upward flame spread velocities etc. of the actual insulation.

1. Introduction

External insulation is a good solution for many buildings as it reduces the effect of cold bridges and in most cases does not need to disturb the inhabitants in the building. It can be used for both single family houses and blocks of flats. In most cases it will change the architecture of the building as we get a new outer layer. This can be a problem for old houses, where we will keep the exterior look. The external insulation can be mineral wool or cellular plastic material covered of an external layer of plate material or plaster. There is a European Technical guideline (ETAG 004 from 2011) for external insulation systems. The systems are called ETICS, an abbreviation for External Thermal Insulation Composite Systems. The guideline describes the tests for each component and the system that has to be done to get a CE-mark. The acceptance of the system is based on the whole system, so it is not allowed just to change for instance the insulation material without a new approval. The European Association for External thermal insulation (EAE) has made a report (EAE 2011) that describes a quality system for external extra insulation. In Denmark it has not been allowed to use plastic insulation as external insulation and an overview of the experience from other countries is interesting. We will specially focus on the use of cellular plastic material and the problems related to fire. But we will also discuss the use of mineral wool and compare systems with plastics and mineral wool, as they have different properties on some important parameters.

2. Components

The systems consist of:

- Adhesive (binds the insulation to the existing wall surface)

- Insulation material
- Anchors (to fix the insulation if the adhesive is not sufficient)
- Base coat of plaster
- Reinforcement (glass fibre mess)
- Top coat of plaster
- Accessories (strips, corner and bottom profiles, expansion profiles etc.)

For anchors a European approval (ETAG 014) defines the properties needed for plastic anchors. For each of the insulation materials are also found European standards that define the tests that have to be done.

2.1 Existing wall

An external insulation can be performed on existing walls. The outer surface material of the wall will influence the solution.

- Heavy constructions. This includes walls of lightweight concrete, concrete and masonry of different types. In these cases it will normally be easy to fix the insulation systems with anchors and/or glue.
- Light constructions. This can be wood, plywood and gypsum. The mechanical strength of the material can be limited and there is a higher risk for movements of the surface. So the fixing is more complicated. In this case it is important to keep water away from the light construction.

In ETAG 004 are described test methods that must be used to evaluate the system for different outer surfaces. In the EAE guide is a check list to avoid mistakes in design and execution.

2.2 Insulation material

The thermal insulation material must have a CE-mark and the most important factor is the thickness and the thermal conductivity. The thermal conductivity shall be declared by the producer. For external insulation we can normally use the declared value as the insulation should be kept dry. The declared values for mineral wool are 0.034 -0.040 W/mK. For cellular plastic materials there is more variation depending on the type – polystyrene, polyurethane, polyisocyanurate or phenol foam. For polystyrene the value will also depend on the production method – expanded polystyrene (EPS) 0.034 – 0.041 W/mK and extruded polystyrene (XPS) 0.025 – 0.038 W/mK. For phenol, polyurethane and polyisocyanurate foam, the values can go down to 0.022 W/mK. This is caused by gases used in the production process. The declared value takes into account the change in gas concentration during the lifetime.

2.3 Fixing system and surface

The insulation must be fixed to the wall without air gab between wall and insulation material, as this will reduce the heat resistance of the system. For EPS or mineral wool it is normal to glue all over the surface or along the borders of each plate and some points in the centre. It is very important to consider details as corners and connections, so thermal bridges are reduced. The insulation layer must be fixed with anchors if the glue is not sufficient. In the description of the ETICS it must be described which type of anchors (and how many) that are needed. Insulation of plastics does not tolerate ultraviolet-radiation as it can degrade the material, so is it important that the surface plaster is put on as soon as possible. For the outermost plaster layer it is important to take into account all the details with windows, doors, overhang, roof connections and all pipes or cables going through the façade. Examples are fixings for outdoor light and ventilation pipes. These points are critical for the risk of driving rain penetrate into the insulation material and hits the surface of the old wall. The EAE guide includes examples of these details, but each producers of a system must show how these details are solved.

3. Thermal properties

The systems must keep the thermal insulation properties over time, so we still get the energy savings we calculated for the system, also after 10-20 years. We will normally expect that if we calculate the transmission heat loss after the European standards then this is a good estimate for the energy savings. It is possible to measure U-values before and after the installation, but it is very difficult in real buildings to be sure that the indoor (and outdoor) climate is the same and the inhabitants behave in the same way. So a theoretical calculation is sufficient, but we have to look at possible problems.

3.1 Change of U-value over time

For most materials there will be no change in thermal conductivity over time. Only cellular plastics with a foam gas that can diffuse out will increase the thermal conductivity over time, but this should be included in the declared conductivity.

3.2 Gaps in the insulation

With air gaps between the insulation material and the wall or between the insulation panels, then cold outer air can flow into the insulation layer, and we do not achieve the expected U-value. This is important to avoid in the construction phase. Furthermore we must ensure that the fixing of the panel not loosen during the lifetime of the system.

3.3 Moisture in the insulation

Moisture in the insulation will increase the U-value. The moisture can come from the outside in the form of driving rain or from the inside, if the moisture barrier is poor. Most critical is driving rain. If the extra moisture only comes in short periods it will probably dry out.

4. Fire properties

Cellular plastics are made of plastic which is foamed by injecting a gas. The final foam material consists of approximately 95-98% gas. Cellular plastic insulations are flammable, unlike mineral wools which are non-combustible. Fire characteristics for cellular plastics are, of this reason, important to investigate. The risk of fire spread, especially vertically from one storey up to the next, is important for practical solutions. An elaboration of fire spread risks requires thermo physic knowledge about ignition temperatures, critical radiation, flame spread velocities etc. Additives as fire retardants could be relevant to slow down the fire speed or reducing the flammability. This is discussed further below.

Cellular plastic insulation materials have very different fire characteristics, and there exist a number of opportunities to improve these through the addition of varying amounts of fire retardants. The plastic-based insulation materials are found in a variety of configurations, which provide different fire properties.

We do not have one common European test method for facades. Some countries apply their own national tests, other utilize test methods, which in principle are developed for other purposes. This applies to the use of the EN 13823 single burning item (SBI) test for construction products` reaction to fire. Sweden and Norway use a Swedish full-scale test (SP Fire 105).

Cellular plastic has a large surface area relative to body mass, i.e. a large specific surface, and the material has great access to oxygen. These factors result in a fast and clean combustion of the material. The cell structure results in a low density of the material and consequently a relatively low energy production by combustion, measured by volume unit (Troitzsch 2004). (DBI 2012) provides an overview of the typical cellular plastic type density, thermoplastic properties and energy, and is summarized below in Table 1.

Material	**Thermo plastic or thermal curing (Rakic 2003)**	**Density (Davies 2001)**	**Energy content**		**Heat conductivity (EST, 2004)**
			Per Mass (Davies 2001)	Per Volume	
EPS	Thermo plastic	20 kg/m^3	40 MJ/kg	800 MJ/m^3	0.035-0.045 W/mK
XPS	Thermo plastic	35 kg/m^3	40 MJ/kg	1400 MJ/m^3	0.025-0.038 W/mK
PUR	Thermal curing	45 kg/m^3	26 MJ/kg	1170 MJ/m^3	0.022-0.035 W/mK
PIR	Thermal curing	45 kg/m^3	24 MJ/kg	1080 MJ/m^3	0.021-0.022 W/mK
PF	Thermal curing	45 kg/m^3	29 MJ/kg	1305 MJ/m^3	0.025 W/mK

Table 1. Overview of selected physical properties of typical plastic-based insulation materials (DBI, 2012).

4.1 Ignition temperatures

The ignition temperature is dependent on whether there is a pilot flame present or not. If the foam only is affected by heat radiation, the possibility of ignition depends on the exposure time, the radiation intensity and the size of the exposed area.

Table 2 from (DBI 2012) shows examples of ignition temperatures and critical thermal radiation of various cellular plastic insulation materials. The critical thermal radiation is the lowest thermal radiation which may cause ignition. Due to the materials very product specific properties, there may be a discrepancy between the table and some product values.

Material	Ignition temperatures			Critical radiation (auto ignition) (Babrauskas 2003)
	With pilot flame (Davies 2001)	Auto ignition (Davies 2001)	Auto ignition (Babrauskas 2003)	
EPS	245-345 °C	490 °C	440-448 °C	27 kW/m^2
XPS	245-345 °C	490 °C	-	-
PUR	285-310 °C	415-500 °C	457-494 °C	22-26 kW/m^2
PIR	415 °C	510 °C	-	23-24 kW/m^2
PF	490 °C	450 °C	-	-

Table 2. Examples of ignition temperatures and critical thermal radiation of the typical cellular plastic insulation materials (DBI 2012).

4.2 Fire retardant

By the addition of a fire retardant (additive) during production, the fire performance of the foam is changed. An additive can be used to alter cellular plastics ability to shrink or melt, char, slow down the fire speed or to reduce the flammability (DBI 2012). For example, the bromide flame retardants are widely used.

It may be noted that, for example ISOBYG`s EPS burn different than normal EPS, due to adding of flame retardant substances, which make the material does not burn in a self-sustaining reaction. That is, it turns off automatically when there is no direct flame exposure (ISOBYG 2012).

There are a large variety of additives. This coupled with a myriad of different combinations and proportions of different types of cellular plastics, makes it very difficult to accurately describe the additives effect on cellular plastics fire performance. Therefore, a fire-related classification of a foam material must be determined on the basis of a test of the exact composition of the foam and additive(s) (DBI 2012).

Fire and flame retardant additives have the greatest impact by initial heating, from small heat sources, i.e. corresponding to fire effects in the early course of the fire. In a fully developed fire, flame retardants have no effect on the fire performance (NFPA 2003).

4.3 Recommendations on the fire domain

The fire risk is not yet fully documented for cellular plastic insulation on facades. The risk of external flame spread seems to be the most critical parameter in this context. It is recommended that flame spread from one storey to the one above, should be further investigated in order to prove a fire safety level according to the Building Regulations. At the moment, there exists only the Nordic SP Fire 105 test, which in fact is developed for other types of facades. By the way the test is not suitable for handling molten material dripping from the burning facade.

5. Long term experience

The Fraunhofer institute of building physics has from 1975 to 2006 made a survey of ETICS systems in Germany, Austria and Switzerland (Künzel et al 2006). This is an investigation of outside plaster systems mounted on buildings from 18 to 35 years ago. The results show that there can be algae on part of the façade, but not very many mistakes in the form of peeling or cracks. The conclusions are that damage of the plaster is less than plaster direct on masonry. There are more algae on ETICS houses. The cost of repair and maintenance is similar to buildings with plaster on masonry. These systems are with 30 to 60 mm insulation on bricks. In Scandinavia it is important with a thicker insulation layer to improve the U-value.

The lifetime for plaster is important as it will give the lifetime for the ETICS systems. The information from literature is that the lifetime is similar to a masonry wall or a wooden panel. In all cases it is assumed that ordinary maintenance is carried out.

In Sweden it has been popular to build high insulated wooden wall with insulation and plaster on the outside as seen in Figure 1. An investigation of 800 buildings (Samuelson and Jansson 2009) shows that moisture will come into the construction. There is damage in 55 % of the buildings, mostly in houses with EPS as insulation. Using mineral wool as insulation reduces the damage to 32%. This is still a very high damage percentage. The problems are related to details as around windows, doors, shading roofs, balconies and cracks in the plaster at fixation of light or sunblinds. Testing the systems before it is used is important and also to reduce the number of special details, where there is a risk of damage. Later reports (Jansson 2011) confirm the results with EPS giving a high risk of moisture problems for light walls.

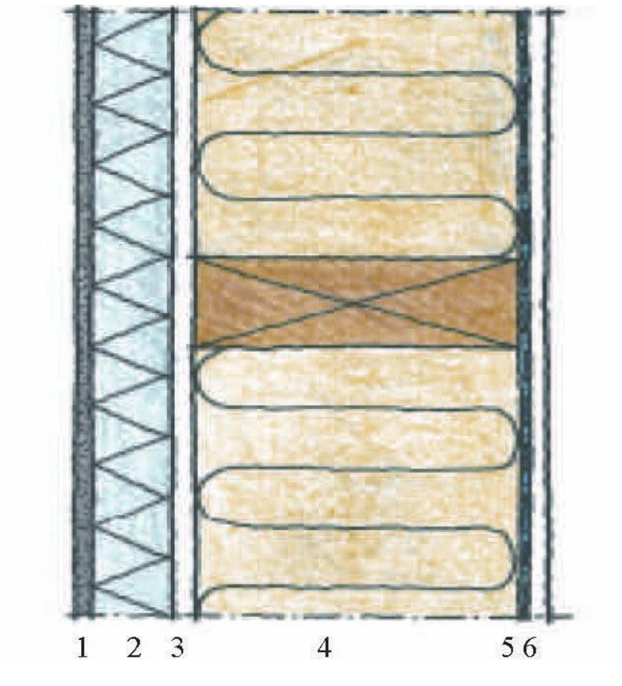

FIG 1. Sketch of system on a light wall from Samuelson 2009, 1- plaster layer 2- external insulation 3 gypsum plate 4 internal heat insulation 5 vapour barrier 6 gypsum plate

The Swedish problems are related to water in the insulation. Drying out of moisture in the external insulation layer is important. The most efficient way is to use a ventilated space behind the plaster or outer plate in the system. Swedish calculations from Falk and Sandin 2013 has shown large variations in drying-out time. The relative drying out time for mineral wool with external plaster layer is 4 times longer than for a ventilated space. For plastic insulation with EPS and external plaster layer the factor is 20-30. So the plastic material increases the drying out time significantly.

6. Conclusion

External insulation of facades has, in Denmark, typically been done with systems of mineral wool as insulation material. This has worked very well, but it is interesting to look at the use of systems with cellular plastic material. Danish experience with plastic material in external insulation system is rather limited, primarily due to limiting building regulations, especially in relation to fire. Experience is taken from Sweden and Germany where it is widespread.

The fire risk is not yet fully documented for cellular plastic insulation on facades. The risk of external flame spread is found to be the most critical parameter in this context. It is recommended that flame spread from one storey to the one above, should be further investigated in order to prove a fire safety level that fulfils the building regulations.

There is no extensive documentation showing that houses with external placed insulation should have a higher general fire risk than buildings without external insulation.

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